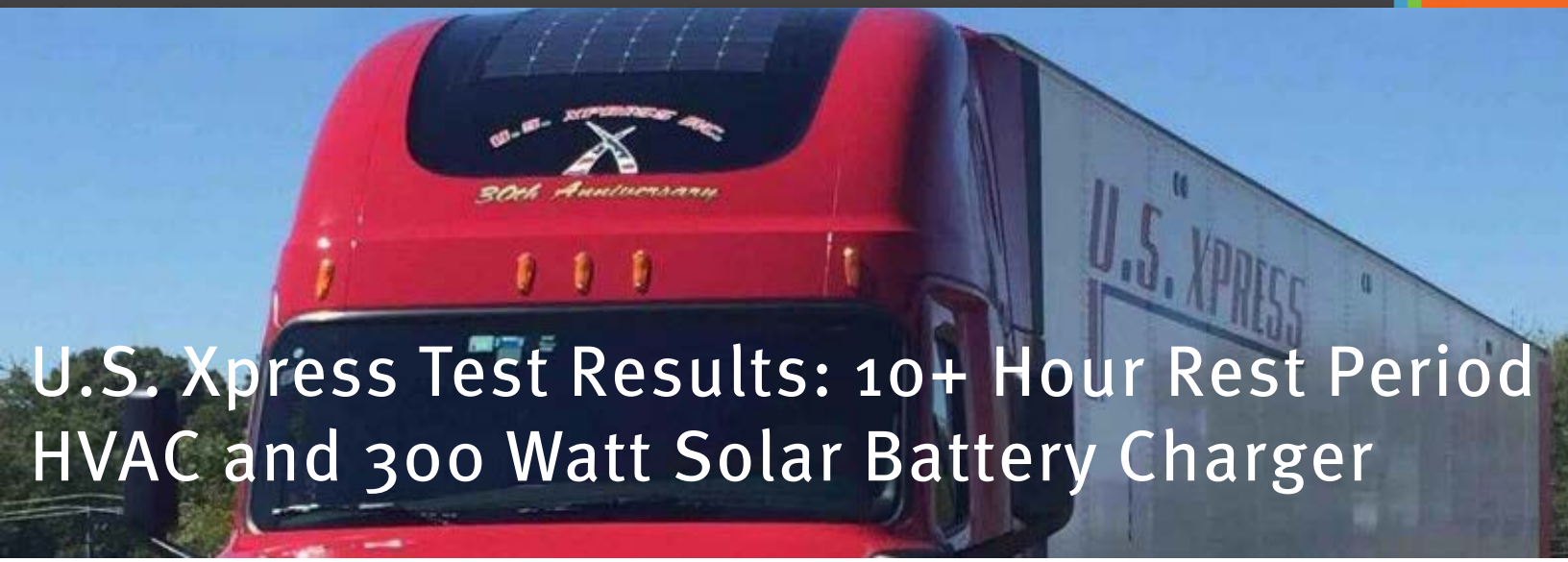
CASE STUDY



U.S. Xpress Test Results: 10+ Hour Rest Period HVAC and 300 Watt Solar Battery Charger

› SUMMARY RESULTS

Over the past several years, eNow, Inc. collected data from a U.S. Xpress Class 8 Sleeper Truck equipped with a battery-powered Air Conditioning (A/C) system and 300 W Solar Battery Charging system during an extended rest period. Based on the data collected during this period, we can conclude:

- A/C with the 300 Watt solar system kept the cabin temperature below 75°F, and usually below 70°F throughout a 10-hour rest period despite outside tractor cabin temperatures that reached well over 100°F. Based on the slope of the discharge, we estimate the A/C could have been run for an additional 1.5 hours.
- Solar connected to the truck battery did effectively charge both the truck battery and auxiliary battery, even during this period of heavy auxiliary load use.
- Solar charge current to the auxiliary battery during the 10-hour rest period was 47 amp-hours, which we estimate to be approximately one additional hour of A/C operation.
- In addition, solar charged the truck battery over the same 10-hour period, keeping the truck battery fully charged at well over 12.8 volts, instead of being depleted by truck parasitic loads.
- Total solar charge current to both batteries could not be quantified, but it was clearly greater than the 47 amp-hours that was transferred to the auxiliary battery.

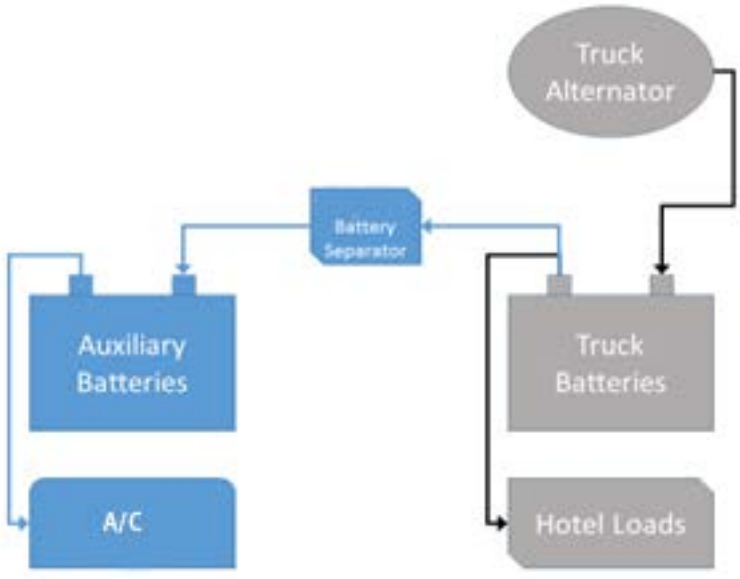
Test and System Design Overview

eNow installed our 300 Watt Solar Battery Charger to power HVAC and other auxiliary loads on a Peterbilt 579 tractor operated by U.S. Xpress. In order to monitor the effectiveness of the system with the addition of solar, eNow installed an Onset HOBO data collector, which records current, voltage, and temperature data from the truck's main (crank or starter) battery and the auxiliary battery banks. The data is sampled from various sensors every 10 seconds, averaged, and logged in 5 minute increments.

Thus, the reading at the time stamp is the average reading for the previous 5 minutes. The data is uploaded to the cloud every hour via the cellular network. If the tractor is not in an area with sufficient cellular coverage, the data is stored until the next good cellular service area is entered. The data may be downloaded into a CSV file format which can be directly opened in Excel. The data can be further analyzed and graphed. Although driver logs were not available during this period, it is our understanding that the tractor was being operated by a team of two drivers in long haul operations in the southern U.S.

Solar and Auxiliary Load Connections

For this installation, eNow's 300 Watt solar panel was mounted on the back half of the tractor's roof air fairing. A two-conductor cable connected the solar panel to eNow's solar charge controller located in the auxiliary battery box. Initially, the solar charge controller attached to the four AGM auxiliary batteries through a very short wire harness. More recently, the solar charge controller connection was moved to the truck batteries as requested by U.S. Xpress. The solar charging does not interfere with battery charging directly from the truck engine's alternator. The HVAC is connected to the auxiliary batteries, but the system has a battery separator (i.e., contactor) that connects the truck batteries to the auxiliary batteries. See Figure 1. Note that in the case of the Peterbilt 579 tractor, the sleeper cabin heater and the inverter (for hotel loads) are connected to the truck batteries instead of the auxiliary batteries.



Battery Separator Operation

The HVAC battery separator has a two-fold purpose; when the truck battery reaches 13.2 volts, the contactor closes and allows the auxiliary battery to be charged from the alternator; when the voltage declines to 12.5 volts the contactor opens to prevent over discharge of the truck batteries when the A/C is running off of the auxiliary batteries. Normally when the A/C is turned on, both the auxiliary and main batteries contribute power to running the A/C. When the main battery drops to 12.5 volts, it disconnects the two battery systems and the A/C only runs off the auxiliary batteries, thus ensuring that the driver will always be able to start the truck. It was never contemplated that the auxiliary batteries could have a voltage higher than the truck batteries as is the case in solar charging.

Solar Connection to Auxiliary Batteries

Solar was originally connected to the auxiliary batteries (see Figure 2a), but, due to the operation of the battery separator, and the fact that the inverter and sleeper cabin heater were connected to the truck batteries, the truck batteries were in jeopardy of being discharged too low to start the engine. Our previous data collection did show some occurrences of the truck battery below 12 volts, indicating a low state of charge. In these cases, there was enough parasitic (e.g., hotel) loads running off of the truck batteries so it dropped below 12.5 volts, thus became disconnected from the auxiliary batteries. The solar continued to keep the auxiliary batteries fully charged, but the truck batteries kept discharging.

The batteries would not be connected again until the engine was started, and the separator sees that the truck batteries are 13.2 volts or higher. Another consequence of the battery separator logic is that the solar isn't charging the truck batteries as often as the auxiliary batteries, which can result in lower solar output when the loads connected to the auxiliary batteries (e.g. A/C) are not being used frequently. Therefore, some fuel economy improvement potential is lost when the solar energy produced cannot be used to offset the truck's engine/alternator fuel consumption.

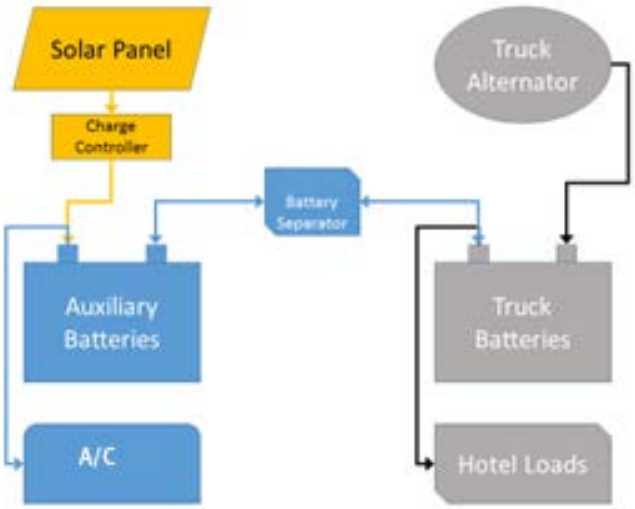


Figure 2a: Solar Connection to Auxiliary Batteries

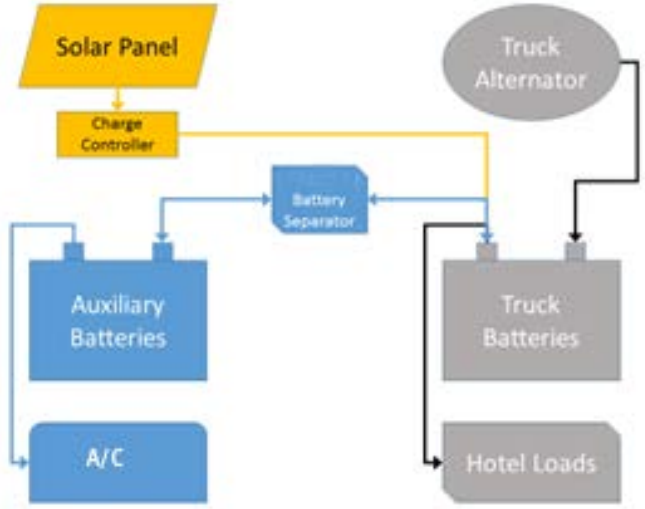


Figure 2b: Solar Connection to Truck Batteries

Solar Connection to Truck Batteries

In order to evaluate a potential solution to the above situation, eNow worked with U.S. Xpress to connect the solar to the main truck batteries instead of the auxiliary batteries (see Figure 2b). This gave priority charging to the truck batteries; and only when they exceed 13.2 volts would the battery separator connect the two battery banks thus charging both systems. It was understood that this solution could give some repetitive cycling of the separator if there is a draw on the auxiliary batteries. When the solar on the main batteries reaches 13.2 volts and closes the contactor; the main battery will move energy to the auxiliary batteries. When the batteries drop to 12.5 volts, the separator would disconnect and the main batteries would charge from the solar until it reached 13.2 volts; then the separator would close and the process would start again. It is believed that this cycling shouldn't cause any harm to the separator.

Performance Results

The A/C was used for an extended period in April, for the first time since the testing began in January. As can be seen in Figure 3, A/C (green line) kept the cabin temperature (blue line) below 75°F, and usually below 70°F throughout a 10-hour rest period despite outside temperatures that reached well over 100°F (red line).[1]

[1] The outside temperature sensor is located in the back of the tractor, about 6 feet off the ground, shielded by a flange of one of the side fairings. Measuring temperature in this way is more representative than just reporting ambient temperature because it measures the actual temperature of tractor body surface.

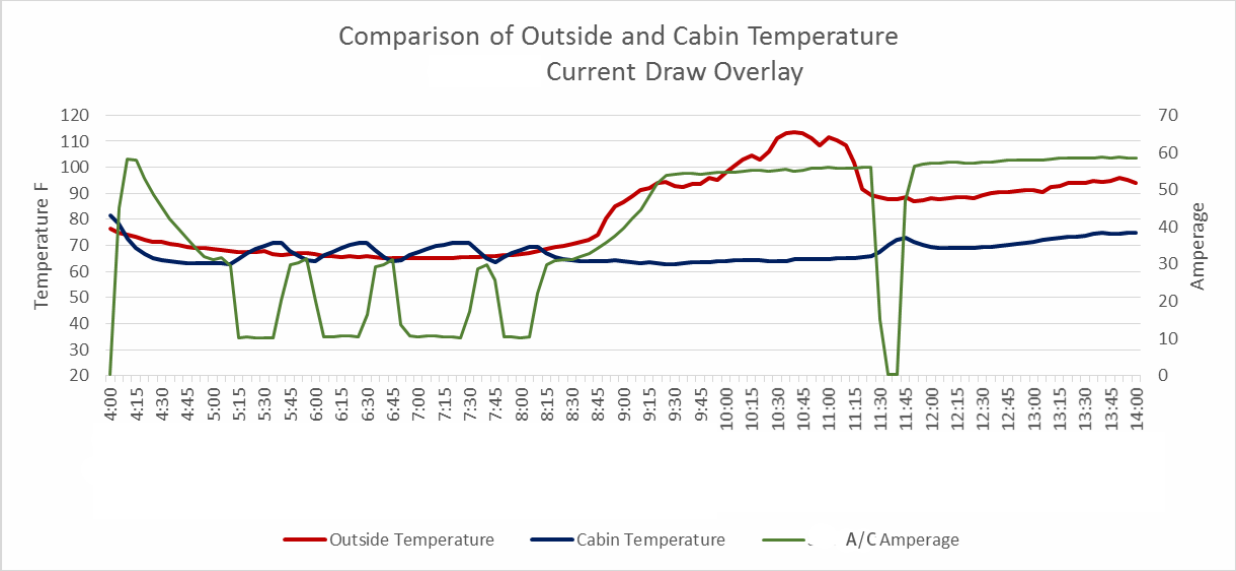


Figure 3: Temperatures and A/C Current Draw

By looking at the battery voltages and A/C current, we can see the state of charge of the batteries and how solar is being used to charge the batteries throughout the 10-hour rest period. As can be seen in Figure 4, the auxiliary battery still had energy left before the A/C was shut off at around 11.5 volts (see point 7 in Figure 4). Based on the slope of the discharge, we estimate the A/C could be run for at least an additional 1.5 hours. We can also see how solar is charging both the truck battery and starter battery through the battery separator. Below is a summary of the rest period referencing each of 7 points on the graph in Figure 4:

1. Rest period begins and A/C turned on. Both auxiliary and truck batteries are connected and contributing to the A/C load. It is at night and the A/C compressor is cycling.
2. Battery voltages approach 12.5 volts and automatically the truck and auxiliary batteries are disconnected from each other in order to protect the truck battery from excessive discharge. The auxiliary battery continues to discharge and, as the sun comes up, more heat load is on the cabin and the A/C draws more current. As the sun comes up, the truck battery starts to charge from solar. The zig zag effect is due to short reconnections of the truck battery to the auxiliary battery.
3. The truck battery gains enough energy from solar so the truck and auxiliary batteries are reconnected. Immediately, the energy is transferred from the truck battery to the auxiliary battery, which increases the auxiliary battery voltage. This continues until the combined battery systems drop to around 12.5 volts and the battery systems are disconnected, again to protect the truck battery from over discharge.
4. A/C is turned off for some reason. The truck battery has enough energy to reconnect to the auxiliary battery and there is energy transfer to the auxiliary battery.
5. A/C is turned on again, the battery voltage drops and the batteries are disconnected.
6. Two more times the batteries are clearly reconnected allowing for additional energy transfer to the auxiliary battery.
7. Rest period ends, A/C is turned off, and the truck's engine is started. Charging is accomplished from both the truck's alternator and solar.

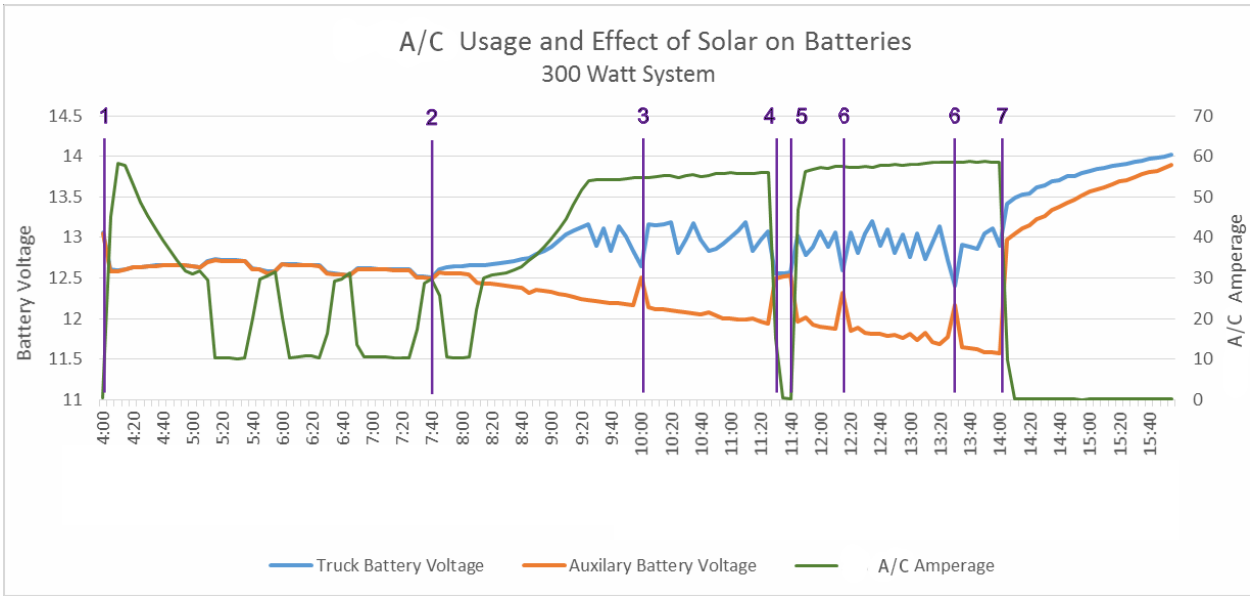


Figure 4: Battery Voltages and A/C Current

In reviewing the transfer of energy between the truck battery and auxiliary battery in Figure 4, it does appear that the batteries are connecting more often than the obvious points (3, 4, 6) in Figure 4. Because the data logger is logging every 5 minutes, it is likely missing the actual connections, but we can see the accumulative solar energy passing to the auxiliary batteries from the current sensor placed between the two battery banks. The amperage transferred from the truck battery to the auxiliary battery from point 2 to point 7 is 47 amp-hours (see Figure 5). On average this would be approximately one additional hour of A/C operation.

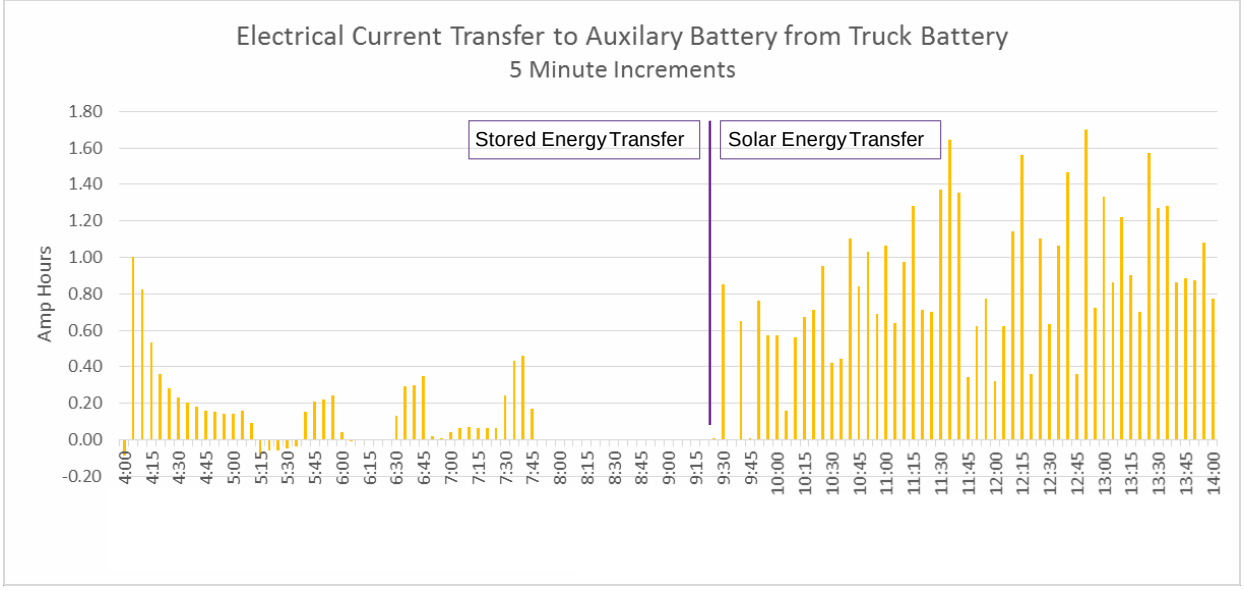


Figure 5: Energy Transfer to Auxiliary Battery

Based on this data, it appears that connecting solar to the truck battery bank allows solar to keep both the truck and auxiliary batteries charged, even during periods of heavy auxiliary load operation. However, the downside is that this approach can result in less solar being used to charge the auxiliary battery and therefore somewhat less A/C runtime than if solar were connected directly to the auxiliary battery, because solar is also being used to power truck battery parasitic loads. To help illustrate this point, we captured a typical parasitic truck battery discharge from earlier data and overlaid it on the data from Figure 4, to see what it would look like if solar was not connected to the truck battery. As can be seen in Figure 6, the truck battery voltage would have probably been around 12.3 volts, instead of fully charged at well over 12.8 volts at the end of the rest period. Therefore, it can be seen that solar is helping power both truck parasitic loads as well as the A/C, and the total solar energy produced is clearly higher than the 47 amp-hours that was transferred to the auxiliary battery.

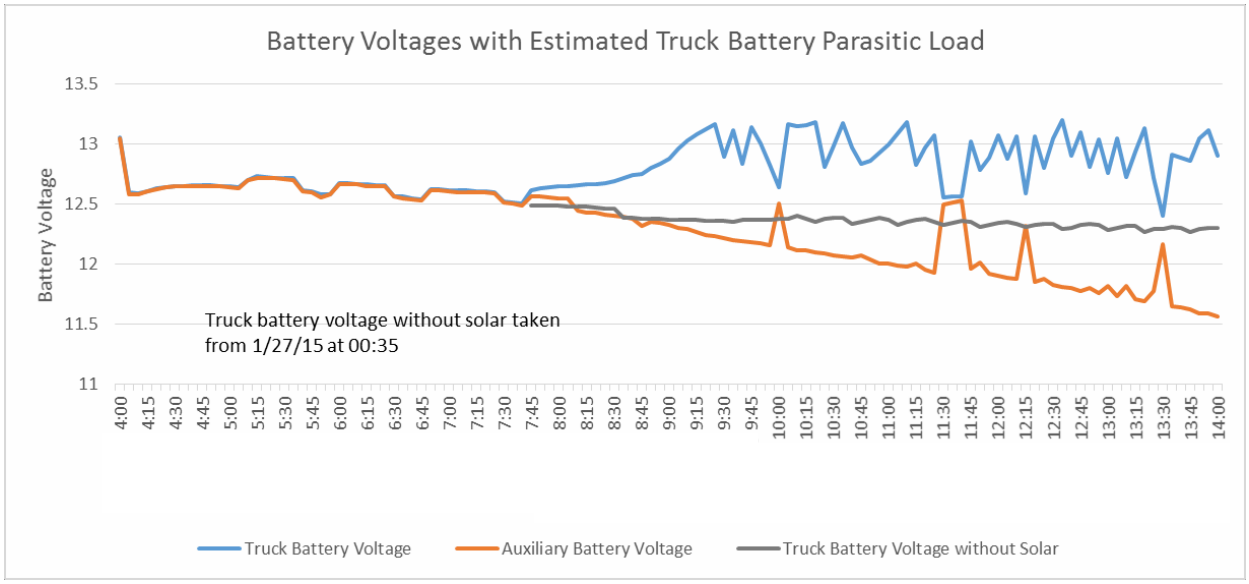


Figure 6: Battery Voltages with and without Solar

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